

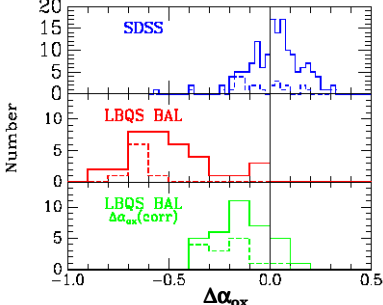
Cosmic Feedback: The Impact of AGN Outflows

Introduction and Motivation

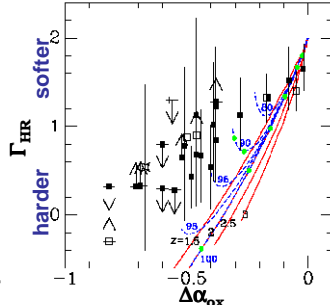
From cosmological simulations, the formation of massive galaxies requires some form of 'feedback' to match the observed properties of local galaxies with the expectations from Λ -CDM models. Outflows from luminous AGNs (quasars) have become the favored mechanism for feedback in massive ($>L^*$) galaxies. Such outflows are directly observed in the $\sim 20\%$ of quasars with Broad Absorption Lines (BALs); these blueshifted features are present in high-ionization UV resonance lines (e.g., CIV, Si IV, Ly α , and O VI) and indicate outflows with terminal velocities of $0.03\text{--}0.3c$. Though the absorption is substantial in the UV, spectroscopic X-ray studies have indicated that the bulk of the absorbing gas is only probed with X-rays.

Characterizing the physical state of the X-ray absorber (including the column density, ionization state, covering fraction, outflow velocity, and location) as well as the outflow energetics are the ultimate goals of X-ray studies of BAL quasars. At present however, only a handful of these typically X-ray faint targets have provided spectra of sufficient quality for detailed analysis. This sample of objects is generally heterogeneous, and thus far, there has been no outstanding predictor of X-ray properties based on UV spectral properties, with the exception that LoBAL quasars (those with Mg II as well as C IV absorption) are exceptionally X-ray faint (e.g., Green et al., 2001, ApJ, 558, 109). To address this issue, we have embarked on a large-scale exploratory X-ray survey of BAL quasars.

Conclusions from Exploratory Chandra BAL Quasar Survey



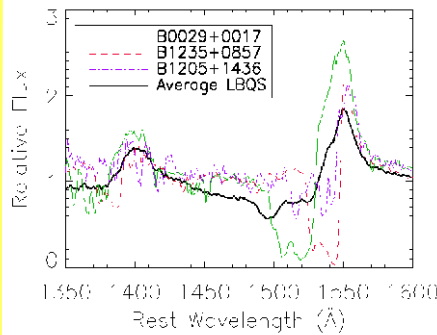
1. BAL quasars are typically X-ray weak, as shown by their distribution of $\Delta\alpha_{\text{ox}}$ values (middle panel). Their median value of $\Delta\alpha_{\text{ox}}$, -0.52 , indicates BAL quasars are ~ 22 times X-ray fainter than normal quasars (top panel; Strateva et al. 2005, AJ, 130, 387). With 4–7 ks *Chandra* observations, 77% of our sample were detected; non-detections are indicated with dashed lines.



2. The distributions of $\Delta\alpha_{\text{ox}}$ (bottom panel, 1) and Γ_{HR} vs. $\Delta\alpha_{\text{ox}}$ indicate that X-ray weakness is primarily due to complex, intrinsic absorption with column densities of $N_{\text{H}} \sim (0.1\text{--}10) \times 10^{23} \text{ cm}^{-2}$. The solid red curves mark the tracks of Γ_{HR} vs. $\Delta\alpha_{\text{ox}}$ for a neutral absorber assuming $\Gamma=2$; blue dashed tracks are for partial-covering, neutral absorbers with f_{cov} labeled in blue.

Sample Selection and X-ray Data

We have compiled a sample of 35 BAL quasars from the Large Bright Quasar Survey (Hewett et al. 1995, AJ, 109, 1498) with $z=1.4\text{--}2.9$ and $M_B \sim -26.1$ to -28.4 . The narrow ranges of both redshift and UV luminosity of this BAL quasar sample make it the largest and most uniform studied with exploratory (4–7 ks) *Chandra* observations to date. In addition to sensitive X-ray data, we also have rest-frame UV spectra for the entire sample, which enable a large and systematic comparison of UV absorption-line and X-ray properties for the first time. The X-ray data that we compile are L_x (the X-ray luminosity), Γ_{HR} (a measure of the X-ray spectral slope, a harder spectrum indicates X-ray absorption), $\Delta\alpha_{\text{ox}} = \alpha_{\text{ox}} - \alpha_{\text{ox}}(l_{2500})$ (the observed slope between the rest-frame 2 keV and 2500 Å flux densities normalized to that expected for normal quasars of comparable UV luminosity), and $\Delta\alpha_{\text{ox}}(\text{corr})$ ($\Delta\alpha_{\text{ox}}$ calculated using the 2–8 keV counts assuming $\Gamma=2$ in an attempt to 'correct' for intrinsic absorption).



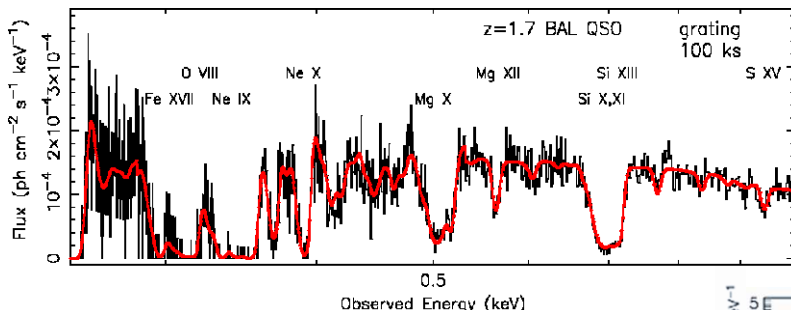
3. Normalized spectra of the CIV region of the three X-ray brightest BAL quasars in the sample compared with the mean BAL quasar spectrum. All three of the X-ray-brightest BAL quasars have relatively narrow, low-velocity troughs.

Implications for Future Studies

In the near future, the X-ray brightest BAL quasars (3 of 35) in this sample are viable candidates for spectroscopy with *XMM-Newton*. However, systematic spectroscopic followup will likely require the next generation of large effective area X-ray observatories such as *Constellation-X*.

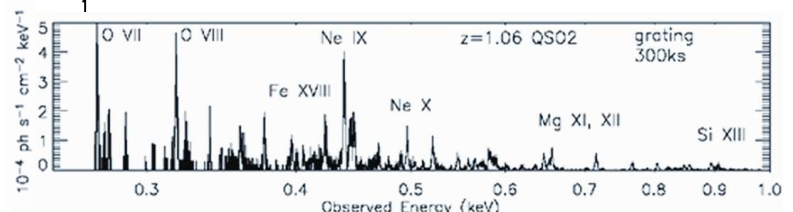
The X-ray brightest BAL quasars are excellent candidates for high resolution X-ray spectroscopy to compare the velocity and ionization structure of the X-ray and UV absorbing gas. Specific predictions based on outflow models for the profiles of X-ray absorption lines would provide important predictions for *Constellation-X*.

Over cosmic time, a significant fraction of the energy from massive black-hole accretion could have been converted into kinetic energy by large-scale outflows, affecting the host galaxies by triggering star formation (by shocking or compressing the interstellar medium [ISM]), or perhaps even shutting it down (by clearing gas from the hosts). Indeed, current large-scale structure simulations require AGN 'feedback' to regulate the growth of massive galaxies. X-rays provide a penetrating probe of all of the material in an outflow, from cool dust through to highly ionized gas. From current X-ray studies of outflows from quasars, it is evident that only high velocity X-ray photoionized outflows can carry enough mass and kinetic energy to affect the ISM significantly. *Constellation-X* spectroscopy will enable the crucial measurements of accretion-related mass-outflow rates needed to determine their importance in massive galaxy evolution.



4. A 100-ks *Constellation-X* simulation of a $z = 1.7$ quasar with an ionized, high velocity outflow and a flux comparable to PG1115+080 (Chartas et al. 2003, ApJ, 595, 85). The solid, red curve shows the two-phase, ionized absorber model (D. Chelouche). Substantial effective area at low energies (0.2–1 keV) is essential; crucial spectral features such as the resonance lines and edges of highly ionized O, Ne, Mg, and Si ($E=0.5\text{--}2.7$ keV) move to lower energies with redshift. These spectral features provide important constraints on the physical conditions in moderate column density gas. In particular, the ionization state, column density, and velocity structure are essential for determining the mass outflow rate. Furthermore, comparisons with the UV absorber properties will enable better understanding of the structure of the multiphase, outflowing wind.

5. Outflows can also be seen in emission in a highly obscured AGN. This simulated 300-ks spectrum demonstrates the capabilities of *Constellation-X* for studying a $z=1.06$ obscured quasar (see Bauer et al., Poster 16.10 for further information on sensitivity limits). Interesting spectral features have been highlighted. The type and quality of spectra shown in 4 and 5 combined with dynamical models of AGN outflows will enable significant constraints to be set on the velocity, ionization state, column density, and location of the bulk of the outflowing gas. These parameters are essential for investigating the nature and kinetic luminosity of quasar outflows.



Acknowledgements

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